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PROTECTION AFFORDED BY [illegible] COVERALLS AGAINST COLD WATER

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NATICK, MASSACHUSETTS

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The Navy Clothing and Textile Research Facility (NCTRF) was contracted by U.S. Coast Guard Headquarters to evaluate the thermal protection afforded by two prototype aircrew anti-exposure coveralls when worn in cold water. The coveralls were developed by two different manufacturers to meet U.S. Coast Guard specification G-OAV-3-1401/A of 15 July 1986. The coveralls were evaluated on seven male subjects immersed in 10°C (50°F) water for 2 hours (with air temperature 13°C, minimal wind). When either of the two anti-exposure coveralls was worn, all subjects were able to complete the 2-hour water immersion. There were no differences in the thermal protection afforded by the two coveralls, as measured by rectal temperature, skin temperature, heart rate, and oxygen uptake responses ($P>0.05$). The decrease in rectal temperature after 2 hours of cold water immersion averaged 1.0°C; mean weighted skin temperature averaged 22.3°C. Final heart rate averaged 77 b/min. Oxygen consumption, which was used as a measure
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of shivering, was the same when either coverall was worn. Both coveralls met the Coast Guard requirement of preventing rectal temperature from dropping more than 1°C per hour. (U)

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THERMAL PROTECTION AFFORDED BY TWO ANTI-EXPOSURE COVERALLS WHEN WORN IN COLD WATER

INTRODUCTION

U.S. Coast Guard Specification G-OAV-3-1401/A of 15 July 1986 describes requirements for a fire retardant, aircrew anti-exposure coverall for wear by helicopter aircrews flying over cold water. In December 1987, Navy Clothing and Textile Research Facility was contracted by U.S. Coast Guard Headquarters to conduct an evaluation of the thermal protection afforded by two prototype anti-exposure coveralls when worn in cold water. The two coveralls were the Model MAC 12 manufactured by Mustang Manufacturing, Inc., of Bellingham, WA and the Model IFS-584 manufactured by Stearns Manufacturing Company, of St. Cloud, MN. Both garments consisted of an aramid fiber outershell with a closed-cell foam interlining. Both had an attached hood (non-insulated) and included hook and pile adjustment straps on the sleeves, legs, and waistband.

METHODS

Subjects

Seven male test subjects participated in the evaluation. They were informed of the purpose and procedures of the study, any known risks, and their right to terminate participation at will without penalty. Each expressed understanding by signing a statement of informed consent. Their age, height, weight, body surface area, and percent body fat are presented in Table 1; percent body fat was estimated from skinfold thicknesses using the equation of Durnin and Womersley (1).

In the present study, subjects wore swim trunks, the anti-exposure coverall, three-finger neoprene mittens conforming to Coast Guard Specification G-OAV-3-1701/B, 75% wool/25% cotton socks (Specification MIL-S-405), insulated rubber boots (Specification MIL-B-41816), and the U.S. Coast Guard survival vest assembly LPU-26/P (Stock Number CG8415-01-171-0771). The arm and leg cuffs of the coveralls were fastened over the mittens and boots, respectively.

Test Design

Testing was conducted in December 1987 in Natick, Massachusetts in the Water Immersion Facility at the Navy Clothing and Textile Research Facility. Testing was conducted according to design and procedures outlined by Headquarters, U.S. Coast Guard. Each of the seven subjects was tested twice, once in each of the two anti-exposure coveralls. The order of presentation of the two coveralls was randomized. Temperature of the water in the immersion tank was 10°C (50°F). Air temperature was 13°C (55°F) with minimal wind (0.5 m/s). Subjects entered the water by climbing down a ladder and floated on their backs with their hands resting on their chest (Figure 1). The combined buoyancy of the survival vest and the foam-insulated coverall resulted in a flotation posture with about 50% of the body above water. Unless termination criteria listed below were obtained, each water immersion test was 2 hours in duration.

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(1) Durnin, J.V.G.A., and J. Womersley. Body fat assessed from total body density and its estimation from skinfold thickness: measurements on 481 men and women aged from 16 to 72 years. Br. J. Nutr. 1974; 32: 77-97.

TABLE 1. Physical characteristics of the subjects

Subject #	Age, years	Height, cm	Weight, kg	Body Surface Area, m^2	% Body Fat *
1	18	170	68.5	1.79	16.3
2	18	183	67.6	1.88	14.1
3	18	170	63.9	1.74	13.0
4	18	170	70.6	1.81	14.6
5	18	185	80.2	2.03	16.0
6	18	169	72.4	1.82	18.6
7	33	170	54.8	1.63	13.9
Mean	20	174	68.3	1.81	15.2
SD	6	7	7.8	0.12	1.9

* From four skinfolds using the equation of Durnin and Womersley (1).

Measurements

Rectal temperature was measured with a thermistor probe inserted approximately 10 cm past the anal sphincter. Skin temperatures were measured with thermistors placed at ten sites: forehead, chest, back, upper arm, forearm, finger, medial thigh, lateral thigh, calf, and toe. Mean weighted skin temperature was calculated using the formula of Teichner (2). Rectal and skin temperatures were printed and plotted every 2 minutes using a computer-controlled data acquisition system (Hewlett-Packard 3054A and 9836). Heart rate was measured from chest electrodes (CM5 placement); heart rate and the electrocardiogram were displayed on an oscilloscope and cardiotachometer unit (Hewlett-Packard 78501A). Oxygen uptake was measured every 30 minutes using an automated metabolic measurement system (MMC Horizon, SensorMedics Corporation). Subjects used a modification of an ASHRAE scale to rate their perception of thermal sensation for their arms, back, chest, face, feet, hands, head, legs, and overall every 30 minutes.

A water immersion test was terminated for any subject: if his rectal temperature fell below 35°C (95°F), if any individual skin temperature fell below 4.5°C (40°F), who voluntarily withdrew, or who was removed at the discretion of the physician on-call or investigator. These safeguards are outlined in the US Army Research Institute of Environmental Medicine Type Protocol for Human Research Studies in the Areas of Thermal, Hypoxic and Operational Stress, Exercise, Nutrition and Military Performance (approved February 1987).

Statistical Analysis

The rectal temperature, mean weighted skin temperature, heart rate, oxygen uptake, and thermal sensation data were analyzed using two-way repeated measures analyses of variance (coverall by time). Tukey's test was used to locate the significant differences. Significance was accepted at the 0.05 level.

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(2) Teichner, W.H. Assessment of mean body surface temperature. J. Appl. Physiol. 1958; 12: 169-176.

RESULTS

Exposure Time

All seven subjects were able to complete each of the 2-hour water immersion tests.

Rectal Temperature

Figure 2 presents the change in rectal temperature from initial values when each of the two anti-exposure coveralls were worn. There were no significant differences in rectal temperature responses between the two coveralls ($P>0.05$). With both coveralls, rectal temperature decreased significantly over time ($P<0.05$). The decrease in rectal temperature over the 2 hours averaged 0.9 and 1.0 ^{o}C for the Stearns and the Mustang coveralls, respectively.

Skin Temperature

Mean weighted skin temperature responses are presented in Figure 3. There were no differences in mean weighted skin temperatures between the two coveralls ($P>0.05$). With both coveralls, skin temperature dropped significantly by minute 20 and thereafter did not change. Final mean weighted skin temperature averaged 22.4 and 22.2 ^{o}C for the Stearns and the Mustang coveralls, respectively.

Heart Rate

As depicted in Figure 4, there were no significant differences in heart rates when the Stearns or the Mustang coverall was worn ($P>0.05$). Heart rates did not change over time ($P>0.05$). Final heart rate averaged 76 and 78 b/min for the Stearns and Mustang coveralls, respectively.

Oxygen Uptake

There were no differences in oxygen uptake when either of the two coveralls were worn ($P>0.05$). Oxygen uptake increased over time ($P<0.05$), from an average of 0.55 l/min during the first 30 minutes, to 0.76 l/min during the last 30 minutes.

Thermal Sensation

Figure 5 presents thermal sensation ratings when each of the two coveralls was worn. Comparing the two coveralls, there were no significant differences in any of the individual or the overall thermal sensation ratings ($P>0.05$). For the overall thermal sensation rating and all of the individual ratings except the head, thermal sensation decreased significantly over time ($P<0.05$). Overall thermal sensation after 2 hours averaged -2.1 for the Stearns coverall and -3.0 for the Mustang coverall.

DISCUSSION

There was no difference in thermal protection afforded by the Stearns and the Mustang prototype anti-exposure coveralls when worn for 2 hours in 10°C water. Both coveralls elicited similar core temperature, skin temperature, and heart rate responses. In the present evaluation, oxygen consumption was measured as an indicator of level of shivering; shivering has been shown to increase oxygen consumption by up to 4-5 times resting levels (3). In this evaluation, oxygen consumption was the same for both coveralls, and increased during the 2-hour water immersion to three times resting levels.

The Coast Guard requirement for thermal protection provided by aircrew anti-exposure coveralls is that the drop in body core temperature while immersed in 10°C water does not exceed 1°C per hour; this must be demonstrated on three male subjects (U.S. Coast Guard Specification G-OAV-3-1401/A of 15 July 1986). In the present evaluation, seven subjects were used. These subjects were of average body fat for males of their age (15%). As depicted in Figure 2, rectal temperature remained stable for the first 20 minutes of water immersion. Excluding the first 15 minutes of water immersion, the rate of cooling up to the first 60 minutes was similar for the Stearns and the Mustang coveralls, and averaged 0.7 and 0.8°C per hour, respectively. The rate of cooling for the second hour of water immersion averaged 0.3 and 0.4°C per hour for the Stearns and the Mustang, respectively (no difference between coveralls). Both the Stearns and the Mustang prototype aircrew anti-exposure coveralls, therefore, met the Coast Guard criteria for thermal protection. Of the seven subjects who participated in this evaluation, none of the individual cooling rates failed the criteria.

Per U.S. Coast Guard specification G-OAV-3-1401/A, acceptance of anti-exposure coveralls is based on body cooling rates during water immersion; the duration of the water immersion test shall be at least 60 minutes. In the present study, each immersion test was 120 minutes. It should be noted that the cooling rate observed during the first hour of immersion was greater than that observed during the second hour. Therefore, cooling rates obtained from water immersion tests of 1 hour duration may not be comparable to those obtained from longer duration tests.

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(3) Hayward, J.S. The physiology of immersion hypothermia. In: Pozos, R.S.; Wittmers, L.E. Jr., eds. The nature and treatment of hypothermia. Minneapolis, MN: University of Minnesota Press; 1983: 3-19.

The thermal sensation data showed no differences between the two coveralls in subjective ratings of thermal comfort. The head and face (which were above the water and therefore exposed to 13°C air) were rated the warmest at "neutral". Hands were "slightly cool", chest and back were "cool", feet, arms and legs were "cool to cold". The overall thermal sensation was "cool to cold".

CONCLUSIONS

In the present evaluation, there were no differences in thermal protection between the Stearns and the Mustang prototype aircrew anti-exposure coveralls when worn for 2 hours in 10°C water. Both coveralls met the Coast Guard requirement of preventing rectal temperature from dropping more than 1°C per hour.

Appendix A. Illustrations

FIG. 1. Test volunteers wearing anti-exposure coveralls in Water Immersion Facility.

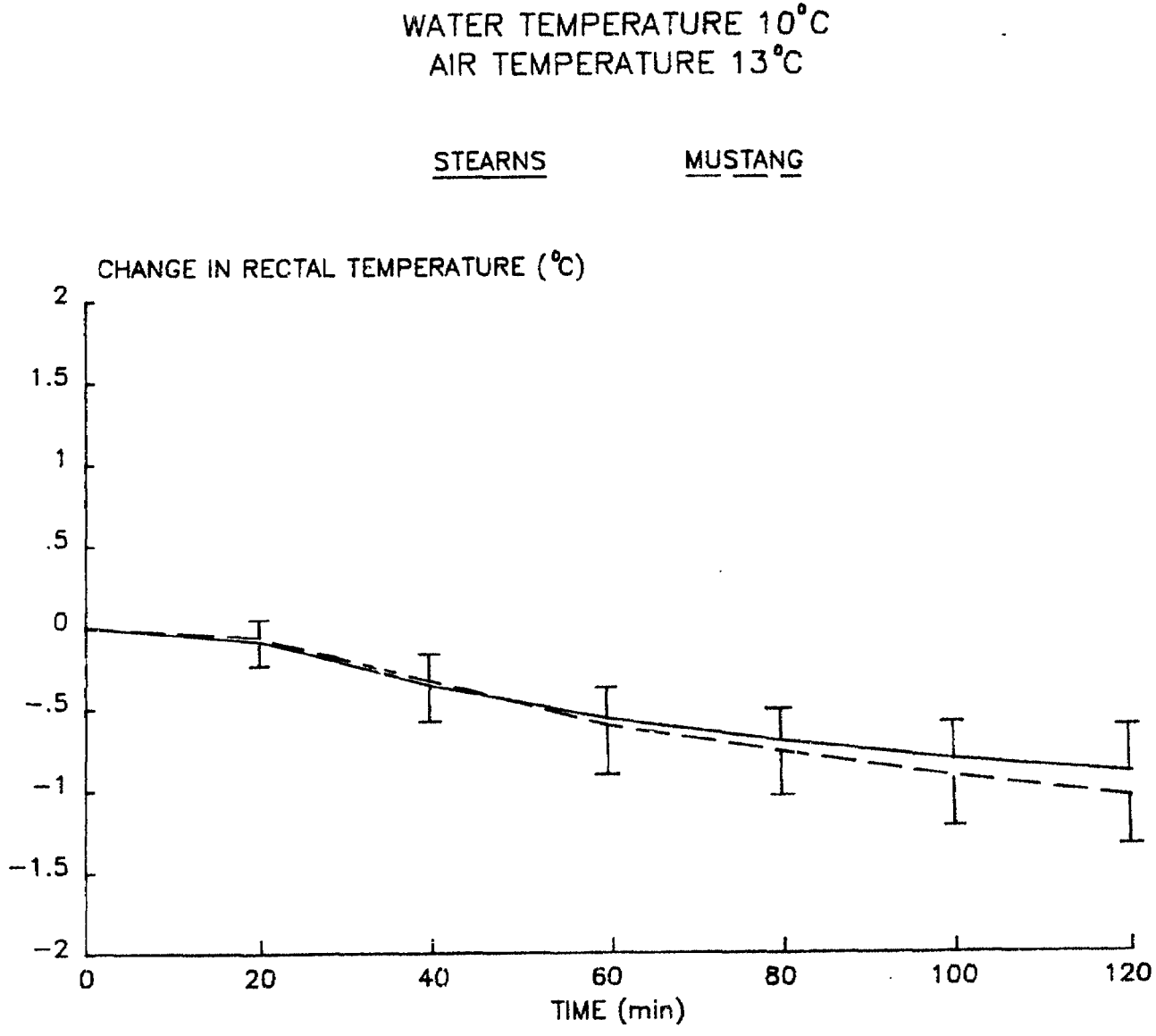

FIG. 2. Change in rectal temperature from initial value for the two coveralls; T indicates SD.

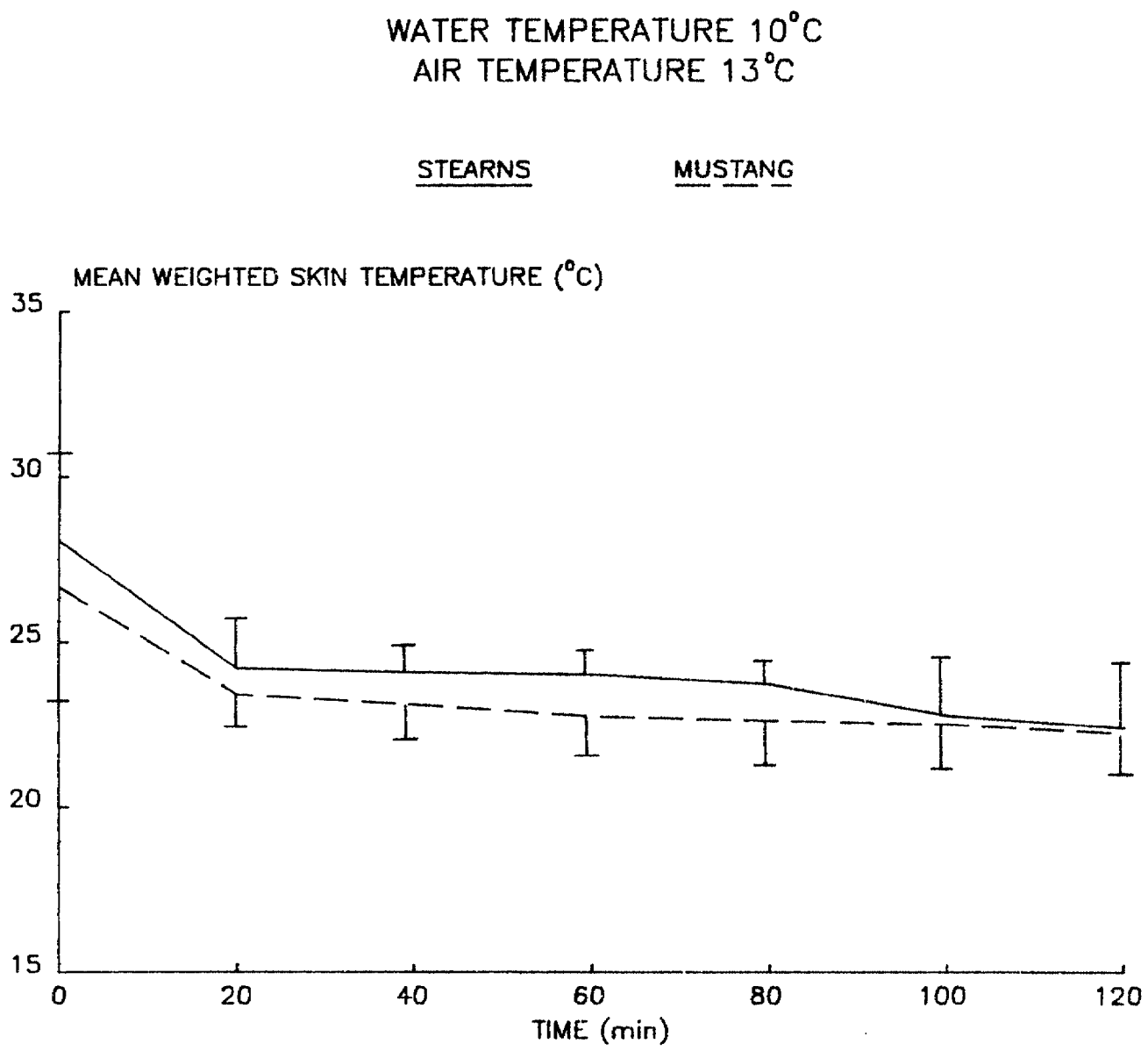

FIG. 3. Mean weighted skin temperature over time for the two coveralls; T indicates SD.

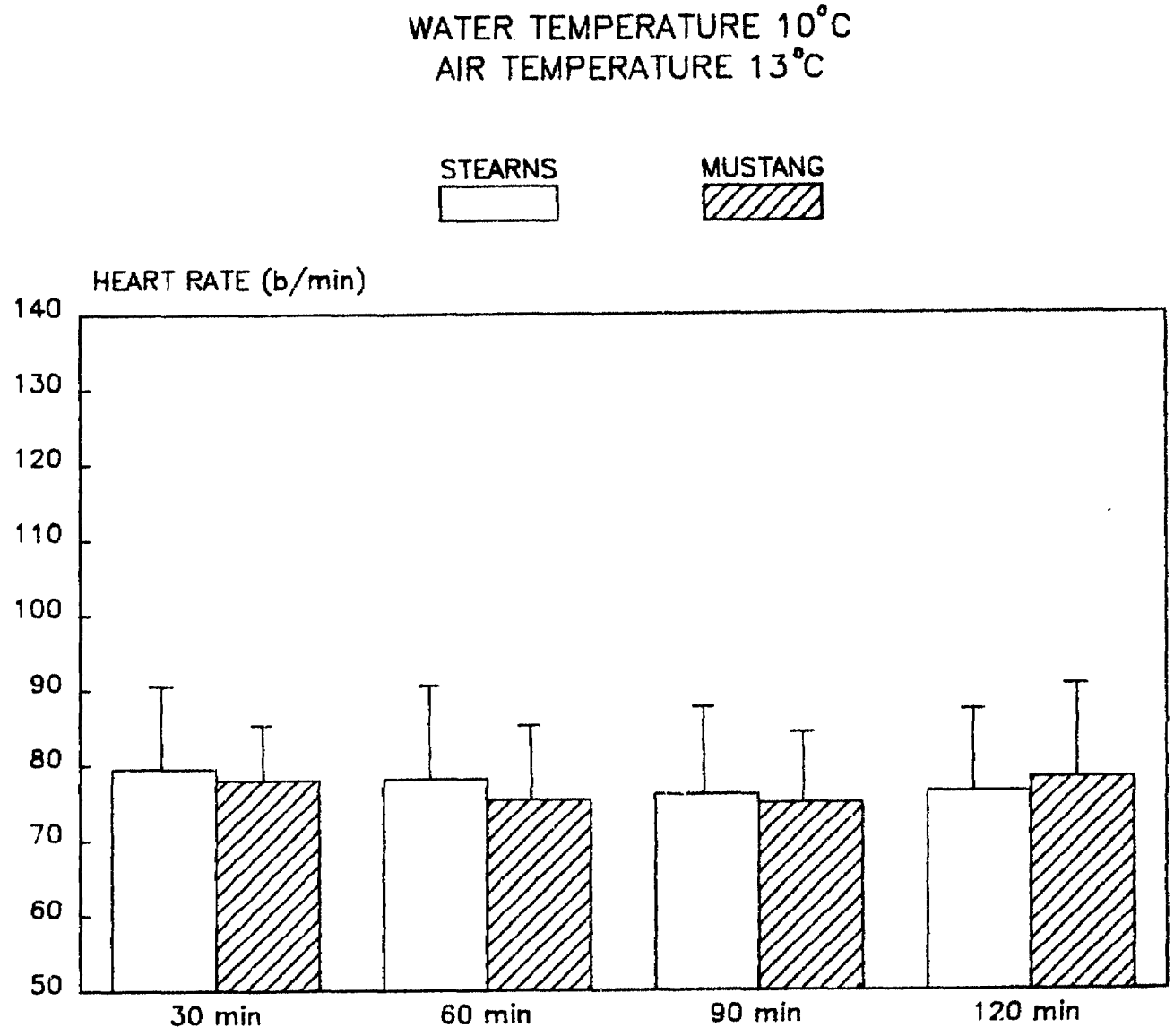

FIG. 4. Heart rate at minutes 30, 60, 90 and 120 for the two coveralls; T indicates SD.

RATING SCALE *			STEARNS		MUSTANG
+4	Very Hot	Head	+0.4	NS	−0.1
+3	Hot	Face	+0.3	NS	−0.1
+2	Warm	Hands	−1.3	NS	−1.1
+1	Slightly Warm	Back	−1.6	NS	−2.0
0	Neutral	Chest	−1.6	NS	−2.1
−1	Slightly Cool	Feet	−1.9	NS	−2.9
−2	Cool	Arms	−2.3	NS	−2.4
−3	Cold	Legs	−2.3	NS	−3.1
−4	Very Cold	OVERALL	−2.1	NS	−3.0

(*Modification of ASHRAE scale)

FIG. 5. Thermal sensation ratings after 120 minutes of water immersion; NS indicates no significant difference between the two coveralls.